HYBRID ESTIMATES OF PATH ATTENUATION FOR THE DPR

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Acknowledgements:
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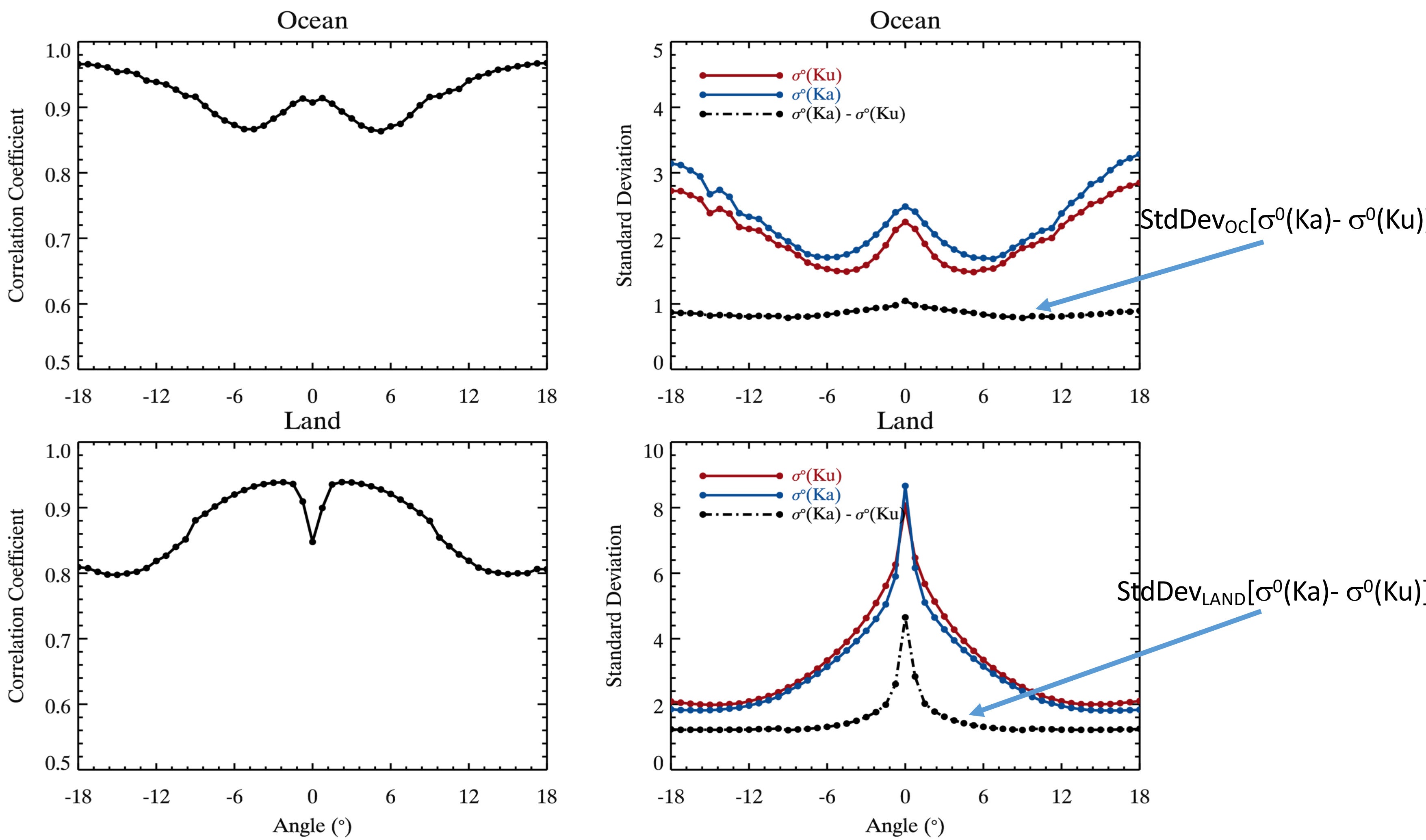
1. NASA/GSFC, Greenbelt, MD
2. Goddard Earth Science Technology and Research, Greenbelt, MD

Outline

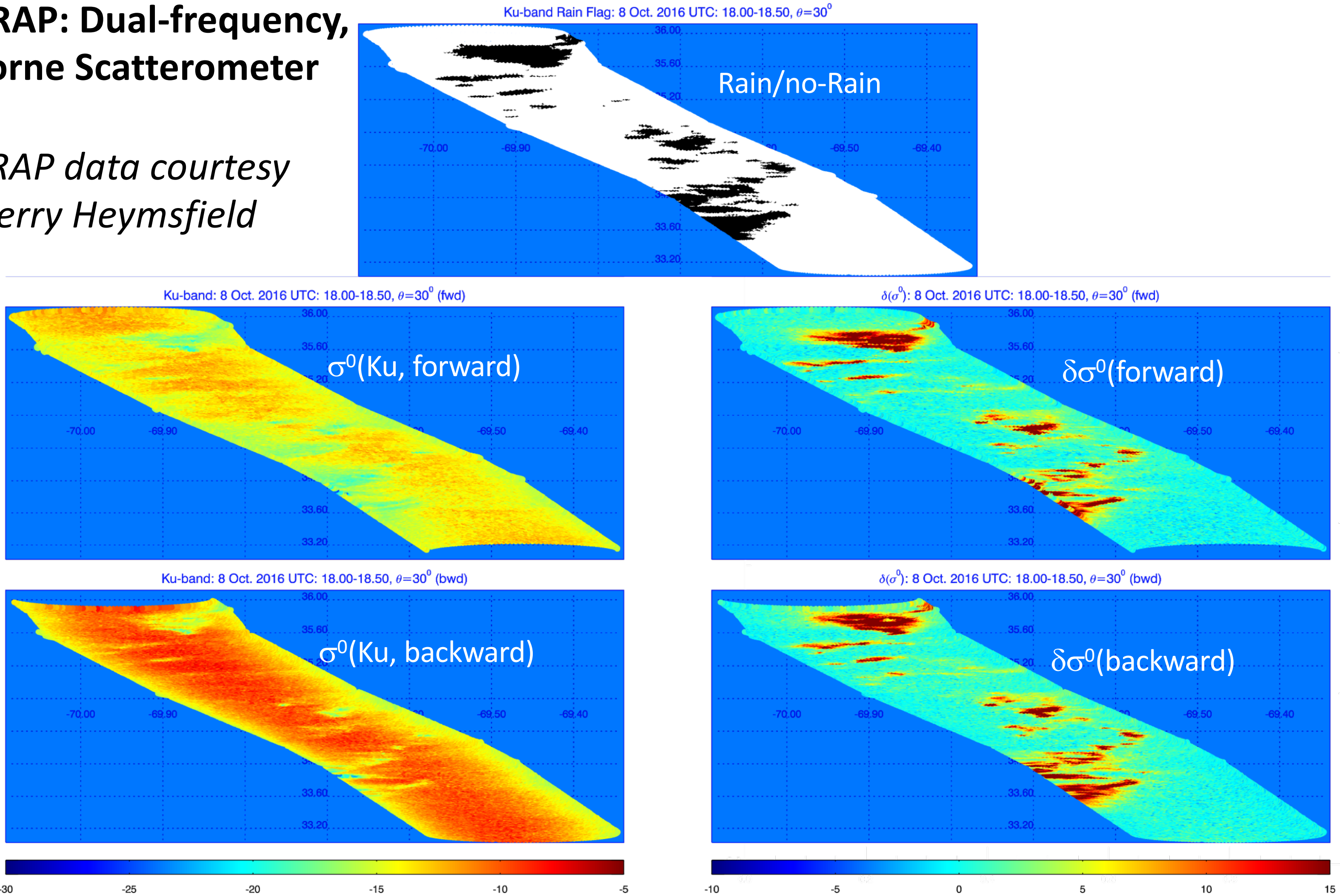
- Some preliminaries on dual-freq SRT
- Hybrid Estimates
- Various Attenuation Techniques
- Results using new Ka-band scan
- Summary

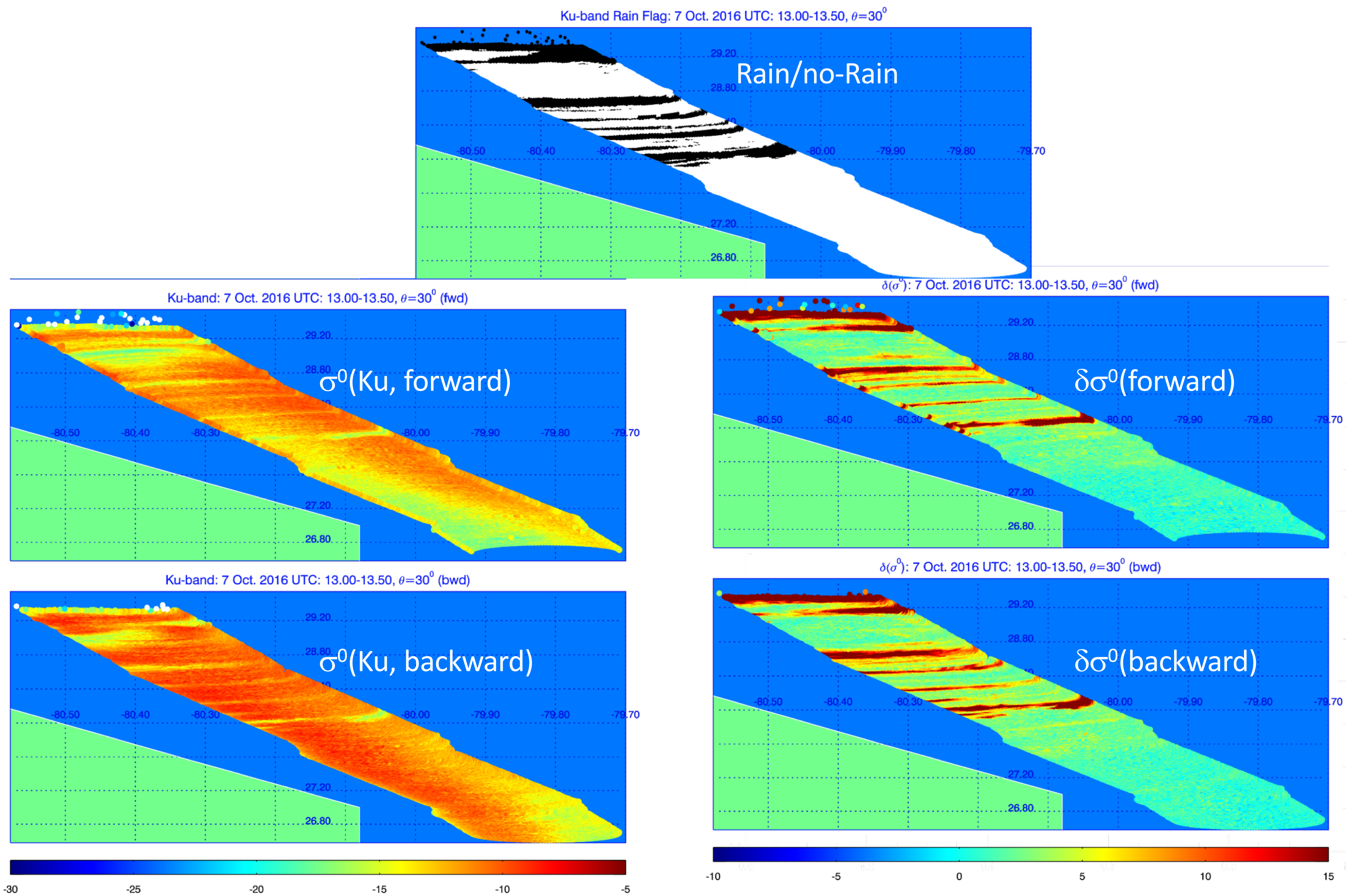
New scan Pattern Ex.(06/2018)



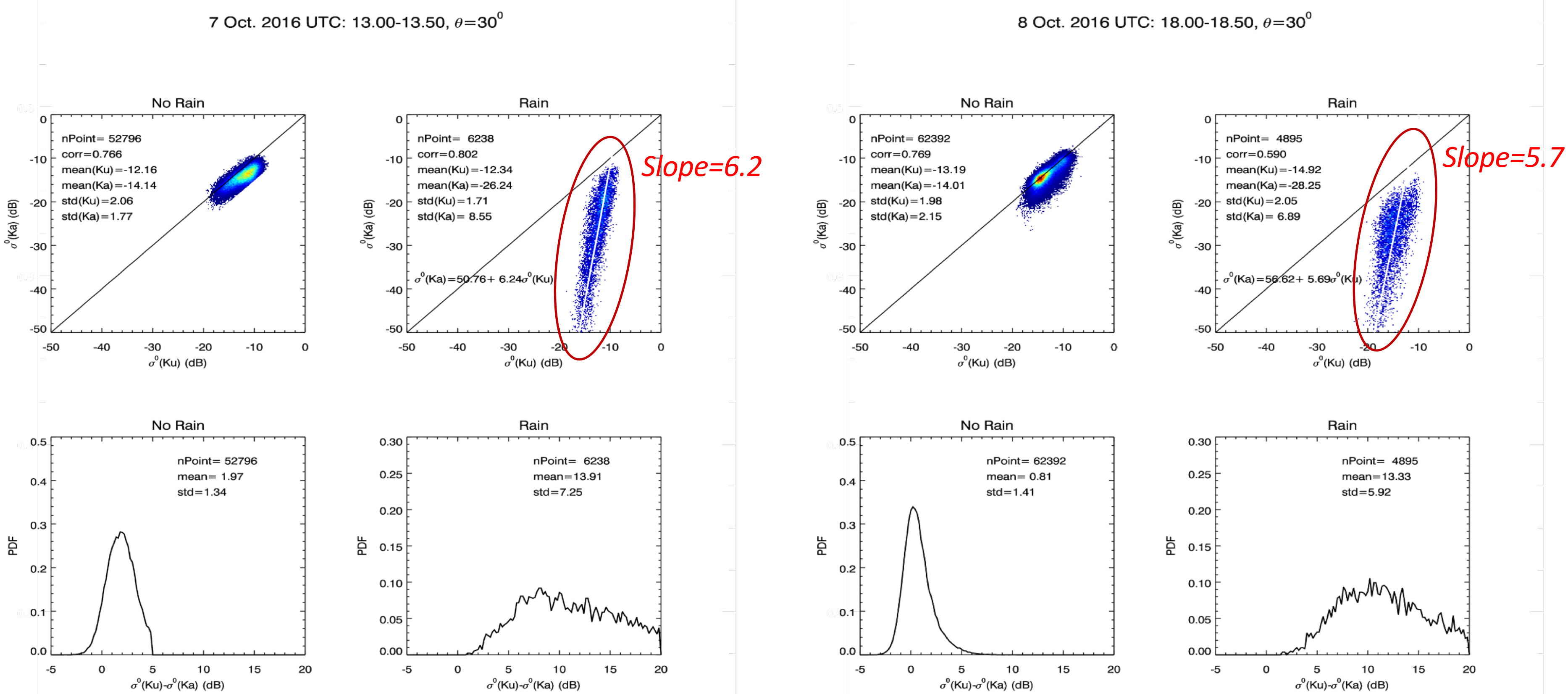
HIWRAP: Dual-frequency, Airborne Scatterometer

HIWRAP data courtesy Dr. Gerry Heymsfield

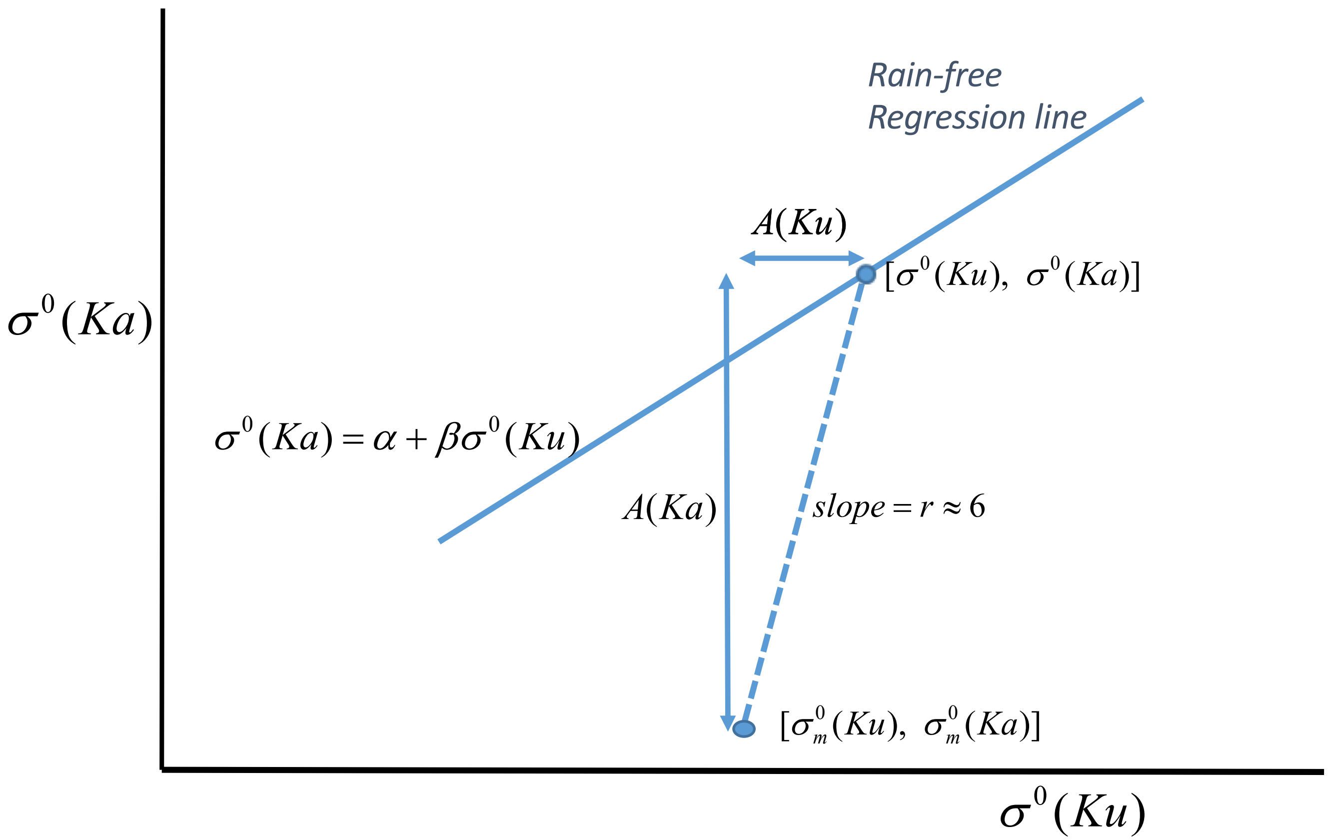




Ku-band Rain Flag: 7 Oct. 2016 UTC: 13.00-13.50, θ=30⁰
Rain/no-Rain
Ku-band: 7 Oct. 2016 UTC: 13.00-13.50, θ=30⁰ (fwd)
σ⁰(Ku, forward)
Ku-band: 7 Oct. 2016 UTC: 13.00-13.50, θ=30⁰ (bwd)
σ⁰(Ku, backward)
δ(σ⁰): 7 Oct. 2016 UTC: 13.00-13.50, θ=30⁰ (fwd)
δσ⁰(forward)
δ(σ⁰): 7 Oct. 2016 UTC: 13.00-13.50, θ=30⁰ (bwd)
δσ⁰(backward)
29.20
28.80
27.20
26.80
-80.50
-80.40
-80.30
-80.00
-79.90
-79.80
-79.70
-30
-25
-20
-15
-10
-5
-10
-5
0
5
10
15



7 Oct. 2016 UTC: 13.00-13.50, θ=30°
8 Oct. 2016 UTC: 18.00-18.50, θ=30°
No Rain
nPoint= 52796
corr=0.766
mean(Ku)=-12.16
mean(Ka)=-14.14
std(Ku)=2.06
std(Ka)=1.77
Rain
nPoint= 6238
corr=0.802
mean(Ku)=-12.34
mean(Ka)=-26.24
std(Ku)=1.71
std(Ka)= 8.55
σ⁰(Ka)=50.76+ 6.24σ⁰(Ku)
Slope=6.2
No Rain
nPoint= 62392
corr=0.769
mean(Ku)=-13.19
mean(Ka)=-14.01
std(Ku)=1.98
std(Ka)=2.15
Rain
nPoint= 4895
corr=0.590
mean(Ku)=-14.92
mean(Ka)=-28.25
std(Ku)=2.05
std(Ka)= 6.89
σ⁰(Ka)=56.62+ 5.69σ⁰(Ku)
Slope=5.7
σ⁰(Ka) (dB)
σ⁰(Ku) (dB)
No Rain
nPoint= 52796
mean= 1.97
std=1.34
Rain
nPoint= 6238
mean=13.91
std=7.25
No Rain
nPoint= 62392
mean= 0.81
std=1.41
Rain
nPoint= 4895
mean=13.33
std=5.92
PDF
σ⁰(Ku)-σ⁰(Ka) (dB)



Rain-free
Regression line
$A(Ku)$
$[\sigma^0(Ku),\ \sigma^0(Ka)]$
$\sigma^0(Ka)$
$\sigma^0(Ka) = \alpha + \beta\sigma^0(Ku)$
$A(Ka)$
$slope = r \approx 6$
$[\sigma_m^0(Ku),\ \sigma_m^0(Ka)]$
$\sigma^0(Ku)$

Attenuation-correction methods available

- Hitschfeld-Bordan |
- Surface Reference | → Hybrid
- Standard Dual-Frequency |
- (Mirror-Image)
- (Polarimetric: $\phi_{DP} \rightarrow A$)
- (Differential-frequency Doppler: $\delta v \rightarrow D_m$)

Hybrid Estimates

- If n independent estimates of a quantity A are available $\{A_1, \ldots, A_n\}$ and if the resultant estimate is written in the form

$$\hat{A} = \sum_{j=1}^{n} w_j A_j$$

Then the minimum variance of the A estimate is obtained by taking (method of Lagrange multipliers)

$$w_j = \tau_j / \sum_{j=1}^{n} \tau_j$$

$$\tau_j = 1 / \mathrm{var}(A_j)$$

Hybrid Estimates - continued

- This implies that the variance of the estimate is

$$\mathrm{var}(\hat{A}) = 1 / \sum_{j=1}^{n} \tau_j$$

which is less than or equal to the variance of any individual estimate.

- This approach is being used for the SRT since we have up to 5 different estimates of the SRT-PIA, depending on the type of reference data used

- The critical issue is to estimate the variances for the HB, SRT & DW
  - (for the SRT, the variance is obtained from the sample variance of the reference data)

Hybrid Estimates - continued

- Explicitly, for the dual-freq case:

$$\delta A_{HY} = w_{SRT}\delta A_{SRT} + w_{HB}\delta A_{HB} + w_{DW}\delta A_{DW}$$

- For the single-freq case, we have only 2 methods:

$$A_{HY} = w_{SRT} A_{SRT} + w_{HB} A_{HB}$$

- Some issues about how best to display the dual-freq results
  - Output files are set up to store Ku or Ka results, not differential
  - δA_{HY}, δA_{SRT}, δA_{DW} are converted to Ku-band by multiplying by 5
  - For HB, we do not retain A_{HB}(Ku) as computed from δA_{HB}

Hitschfeld-Bordan

- With a k-Z relationship and the measured radar reflectivities, Z_m, along the radar beam, an estimate for the attenuation-corrected radar reflectivity, Z, & path attenuation, A (δA), can be made

$$Z(r) = Z_m(r) / [1 - \zeta(r)]^{1/\beta}$$

$$A_{HB}(r_{ns}) = -(10/\beta)\log_{10}[1 - \zeta(r_{ns})]$$

$$\delta A_{HB}(r_{ns}) = 10\log_{10}[(1 - \zeta(r_{ns}, Ku))^{1/\beta(Ku)} / (1 - \zeta(r_{ns}, Ka))^{1/\beta(Ka)}]$$

$$\zeta(r_{ns}) = 0.2\beta \ln 10 \int_0^{r_{ns}} \alpha(s) Z_m^{\beta} ds; \quad k = \alpha Z^{\beta}; \quad \delta A \equiv A(Ka) - A(Ku)$$

Hitschfeld-Bordan - continued

- Estimate becomes unstable as attenuation increases
  - As $\zeta \rightarrow 1$, $A \rightarrow \infty$ (less useful at Ka-band than at Ku-band)
- Estimate depends on radar calibration
- Since α (in k-Z relationship) depends strongly on phase state, knowledge of hydrometeor phase state along the path is important
  - This can be a significant problem in convective rain where mixed-phase layer is often not apparent
- Estimate is sensitive to non-uniform beam-filling (NUBF)

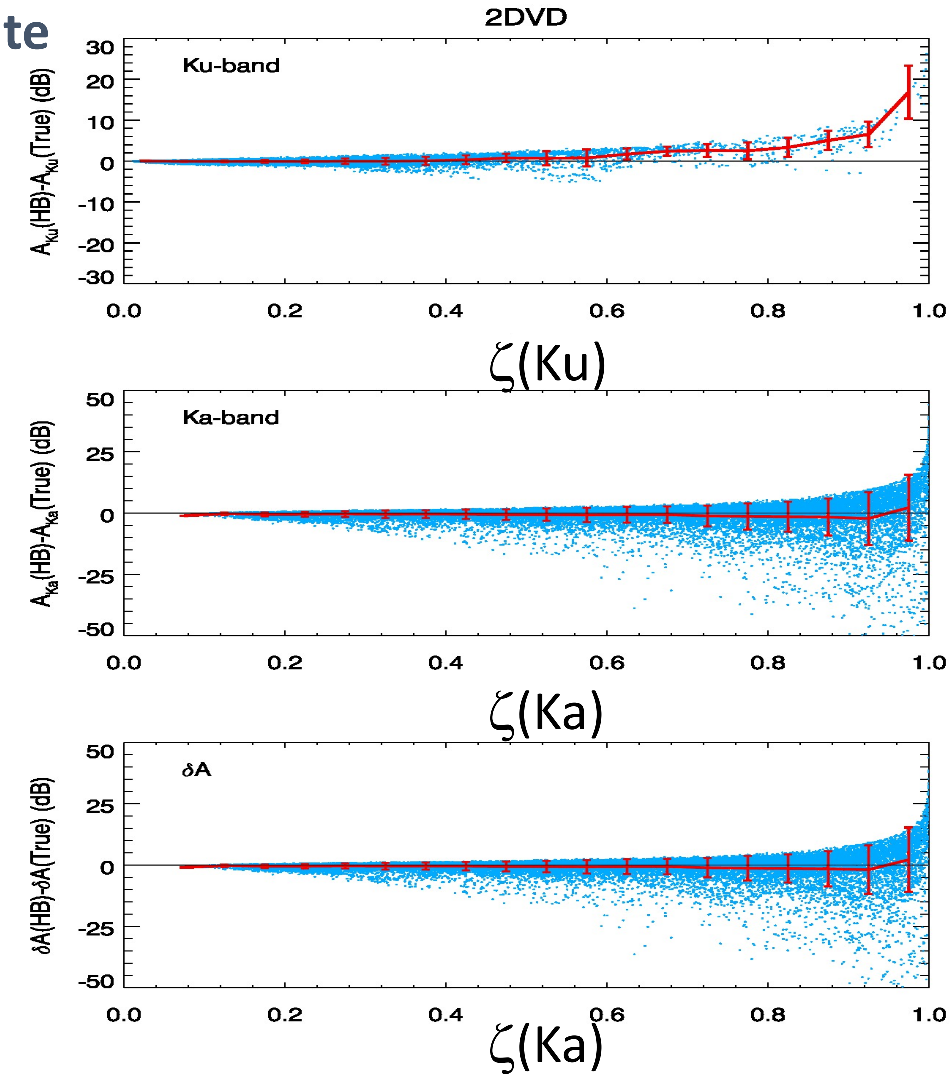
Estimating error var of HB-PIA estimate

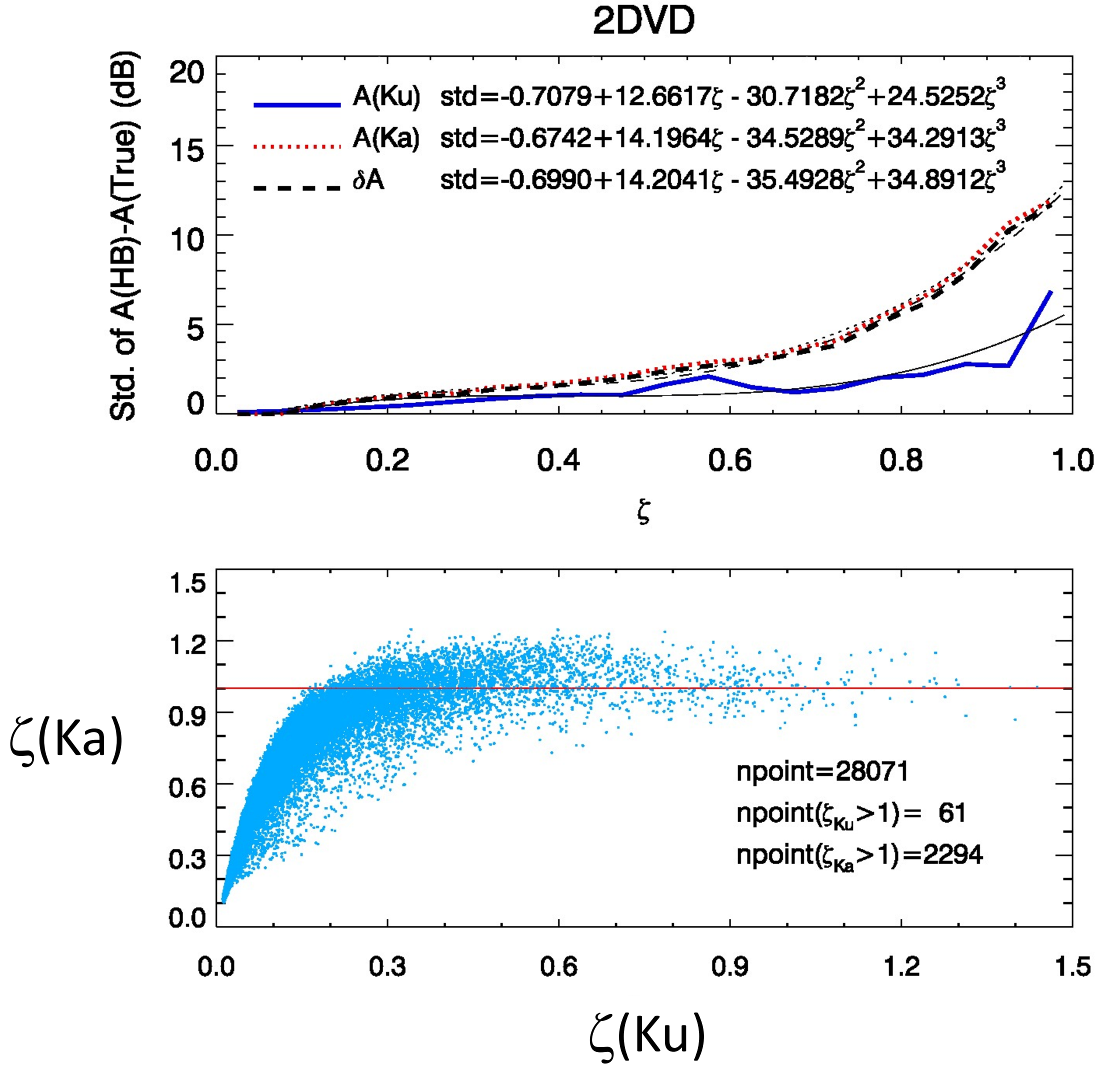
Use a temporal sequence of DSD’s to represent DSD along path of the DPR

Compute α, β in k-Z relation from the full set of DSD data

Compute HB-PIA and true PIA for each sequence/path

Compute the mean & std dev of the difference between the two




2DVD
Std. of A(HB)-A(True) (dB)
A(Ku) std=-0.7079+12.6617ζ - 30.7182ζ^2+24.5252ζ^3
A(Ka) std=-0.6742+14.1964ζ - 34.5289ζ^2+34.2913ζ^3
δA std=-0.6990+14.2041ζ - 35.4928ζ^2+34.8912ζ^3
ζ
ζ(Ka)
npoint=28071
npoint(ζKu>1)= 61
npoint(ζKa>1)=2294
ζ(Ku)

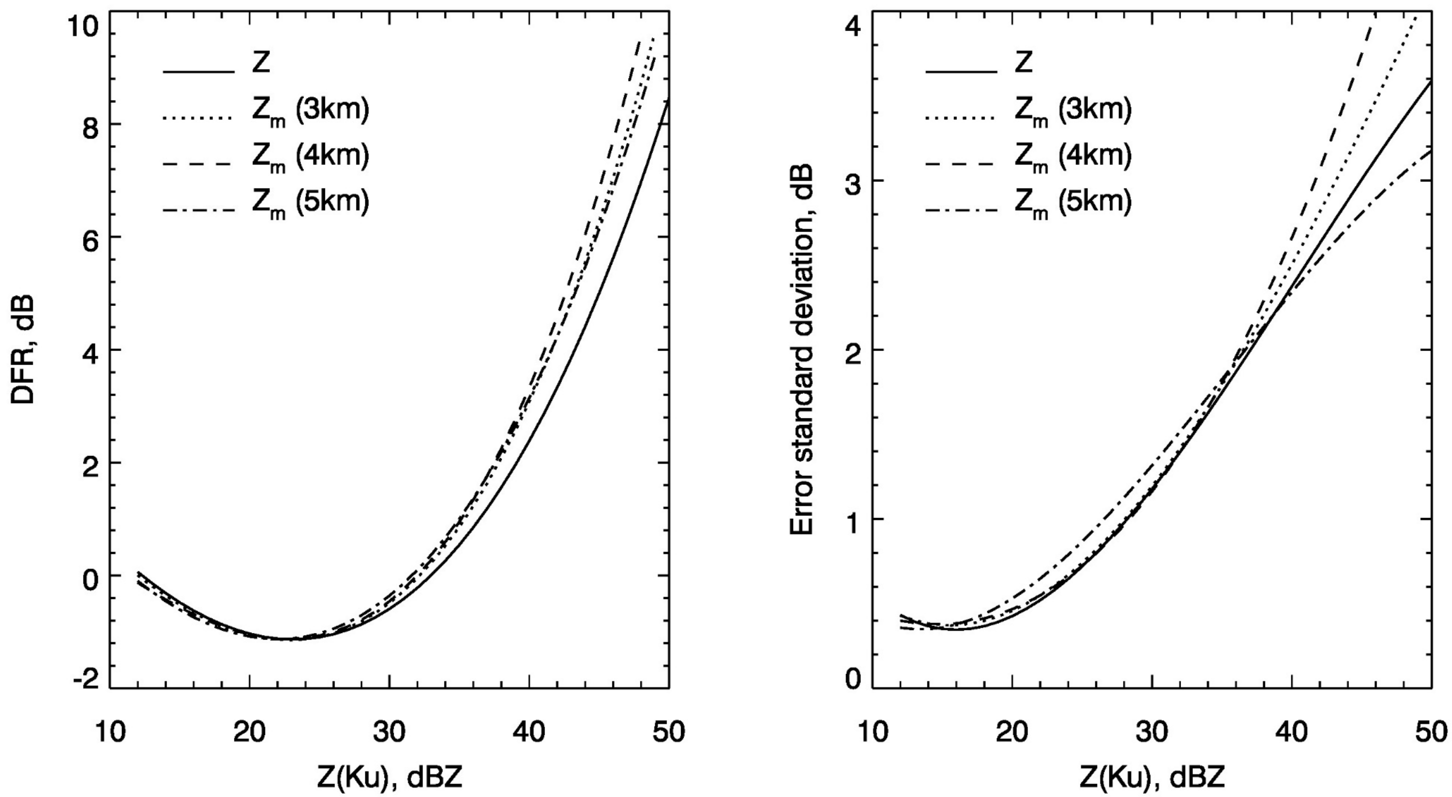
Standard Dual-Frequency

- The differential path attenuation is equal to the difference between the measured, DFR_m, and actual dual-frequency ratio, DFR
  - This follows directly from the definitions of these terms
  - To a first approx., the DFR can be neglected
  - To a second-order approx., the DFR can be estimated from dBZ_m (near surface)

$$\delta A_{DW}(r_{ns}) = DFR_m(r_{ns}) - DFR(r_{ns})$$

$$\delta A_{DW}(r_{ns}) \approx [dBZ_m(Ku, r_{ns}) - dBZ_m(Ka, r_{ns})] - DFR(dBZ_m(Ku, r_{ns}))$$

  - Largest error source is in approximating DFR
  - Method should be less sensitive to NUBF than either HB or SRT



Z
Zm (3km)
Zm (4km)
Zm (5km)
DFR, dB
Z(Ku), dBZ
Error standard deviation, dB
Z(Ku), dBZ

Surface Reference Technique

- Given measurements of the normalized surface cross section inside and outside the rain, $\sigma^0(\text{rain})$, $\sigma^0(\text{no-rain})$, an estimate of path attenuation (& differential path attenuation) is

$$A_{SRT} = \sigma^0(no - rain) - \sigma^0(rain)$$

$$\delta A_{SRT} = \delta\sigma^0(no - rain) - \delta\sigma^0(rain)$$

$$\delta\sigma^0 = \sigma^0(Ka) - \sigma^0(Ku)$$

$$\delta A = A(Ka) - A(Ku)$$

Surface Reference Technique - continued

- Estimate is sensitive to fluctuations in σ^0 ($\delta\sigma^0$)
  - Errors depend on incidence angle & surface type
  - Fluctuations in $\delta\sigma^0$ tend to be smaller
    - high correlation between σ^0(Ku), σ^0(Ka)
- Estimate is highly sensitive to NUBF
- Estimate is independent of radar constant

$$\mathrm{var}(A_{SRT}) = \left[\sum_j \tau_j\right]^{-1} + \varepsilon; \qquad \tau_j = 1/\mathrm{var}(A_j)$$

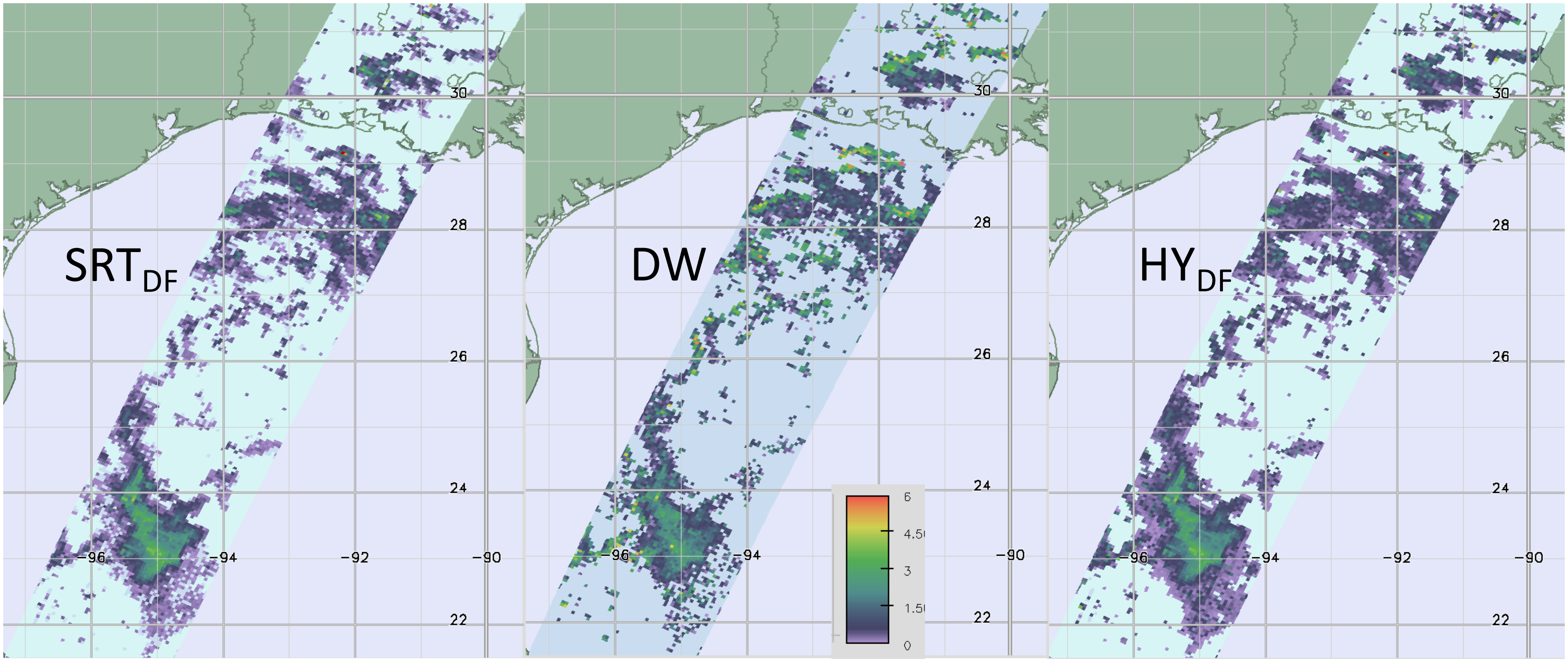
$$\mathrm{var}(\delta A_{SRT}) = \left[\sum_j \tau_j\right]^{-1} + \varepsilon; \quad \tau_j = 1/\mathrm{var}(\delta A_j)$$

$$\varepsilon = \sum_j \tau_j (A_{SRT} - A_j)^2 / \sum_j \tau_j$$

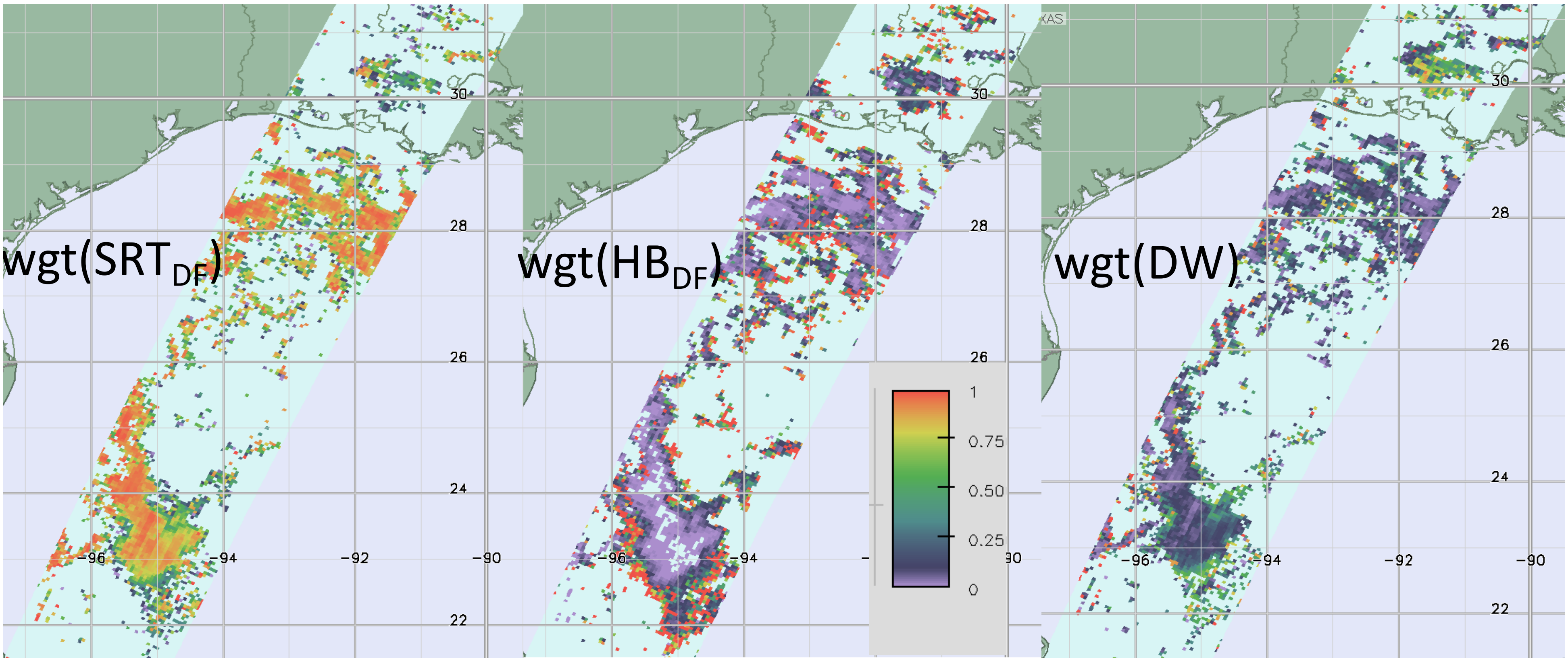
$$\varepsilon = \sum_j \tau_j (\delta A_{SRT} - \delta A_j)^2 / \sum_j \tau_j$$

Case 1

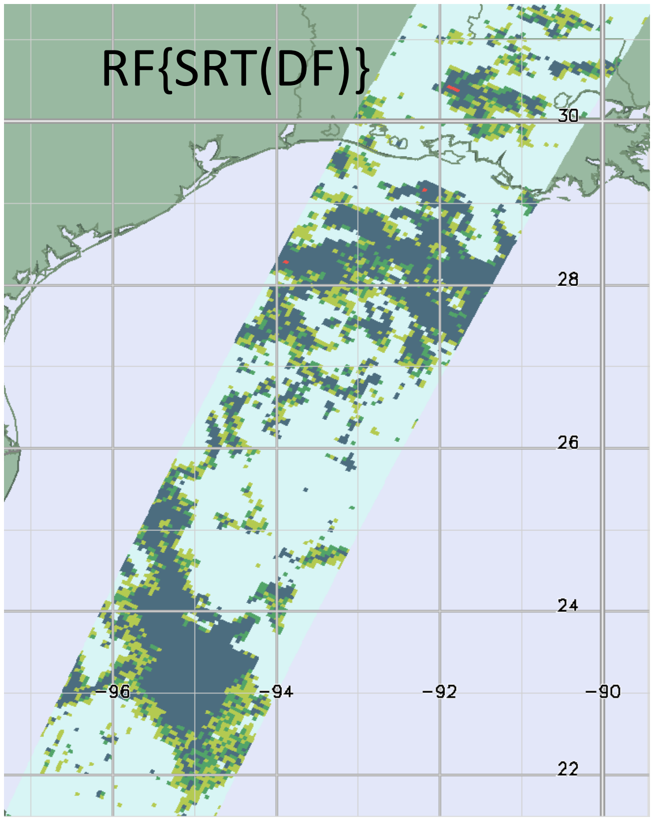
- Orbit: 25811
- Date: 2018/09/13
- Location: Gulf of Mexico
- New Ka-scan

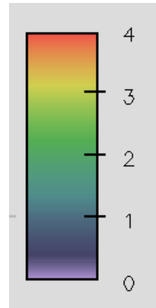


Ku-band PIA from Dual-Freq Methods
(HB_{DF} used in hybrid but not shown/saved)



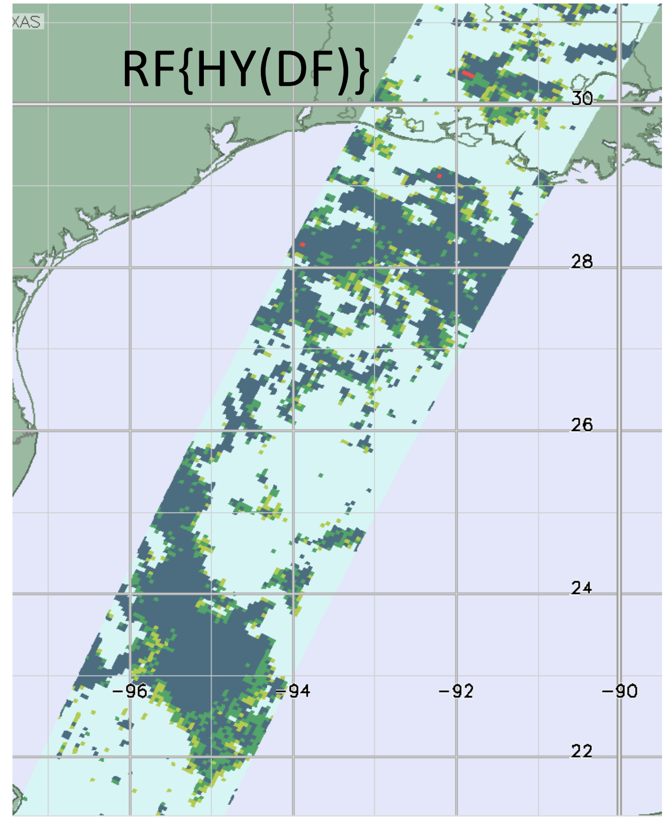
Weight factors used in Dual-Freq Hybrid Estimate of Ku-band PIA



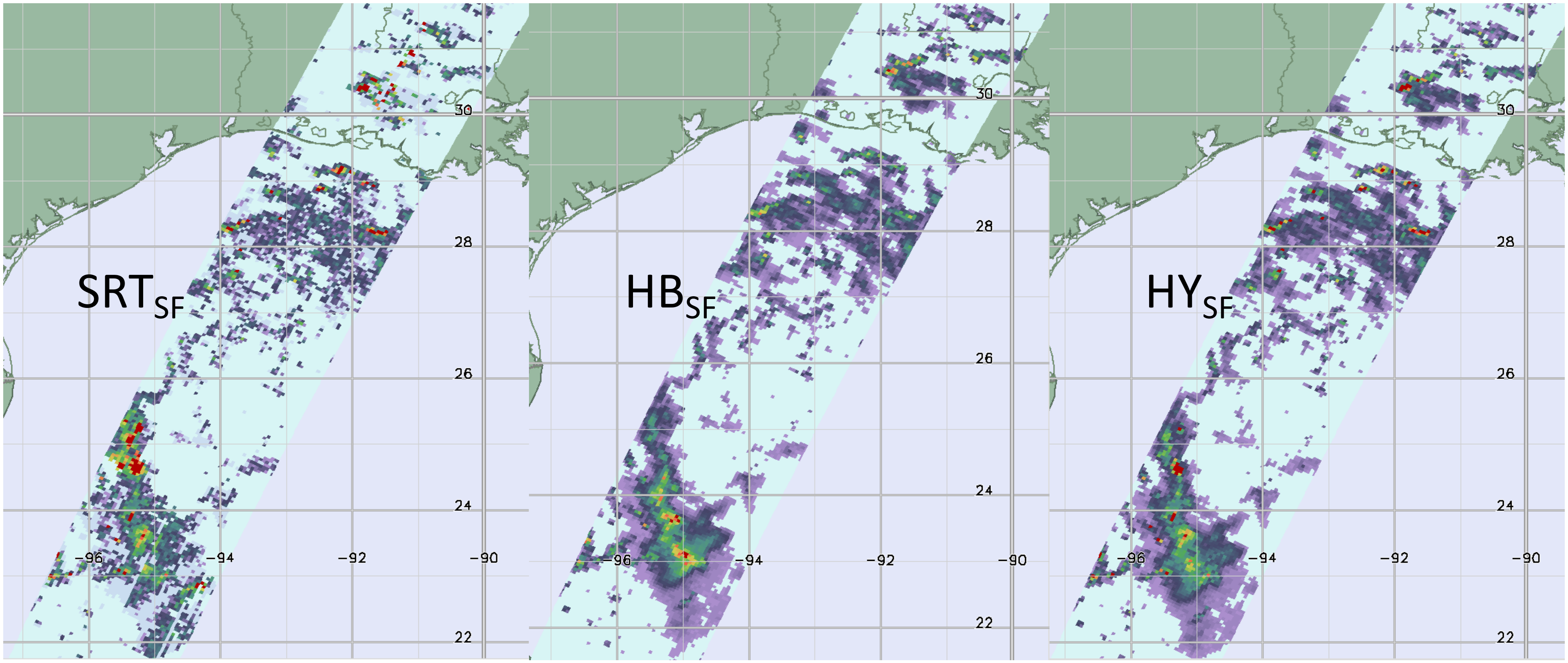


r = E(A)/std(A)

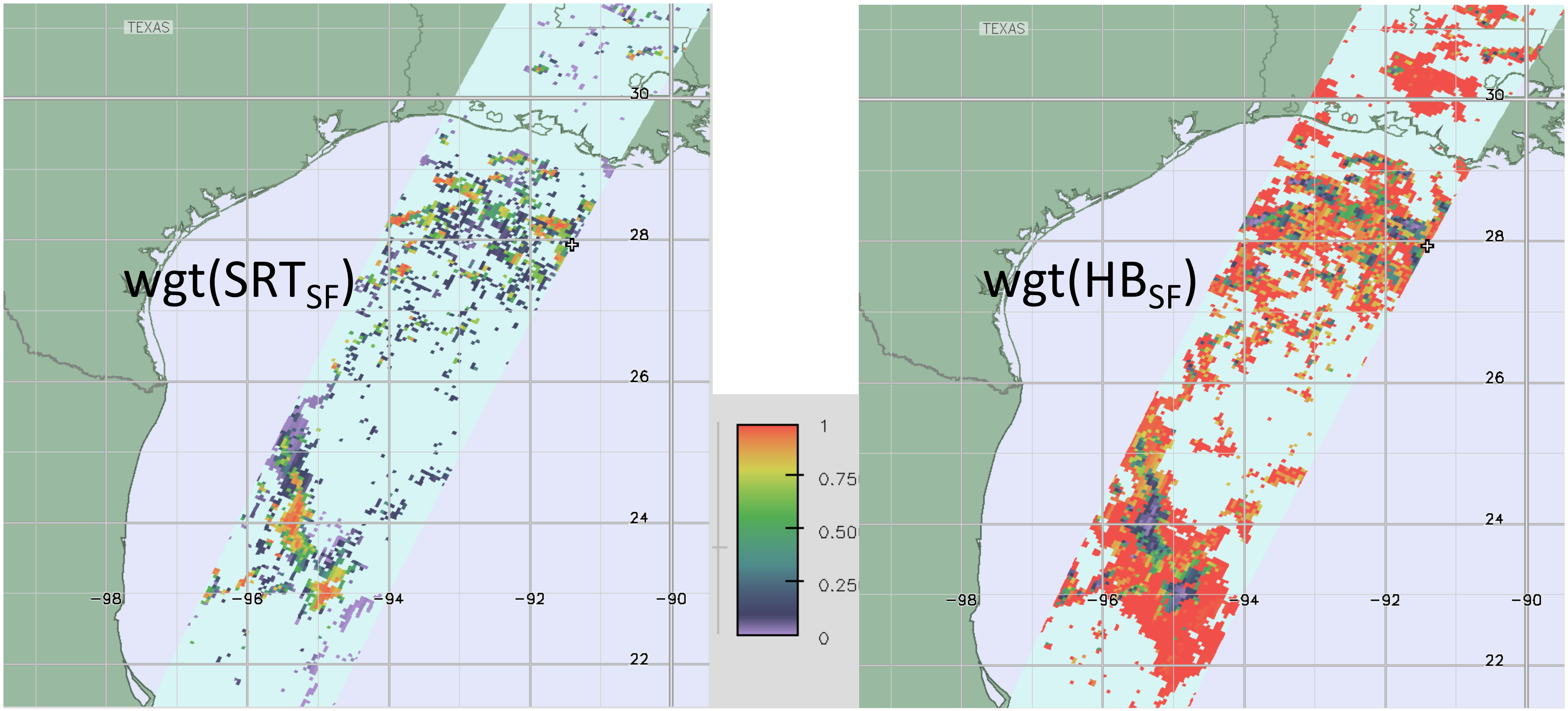
RF=1 if r>3 (blue)
RF=2 if 1<r<3 (green)
RF=3 if r<1 (yellow)
RF=4 if SNR<2 (red)



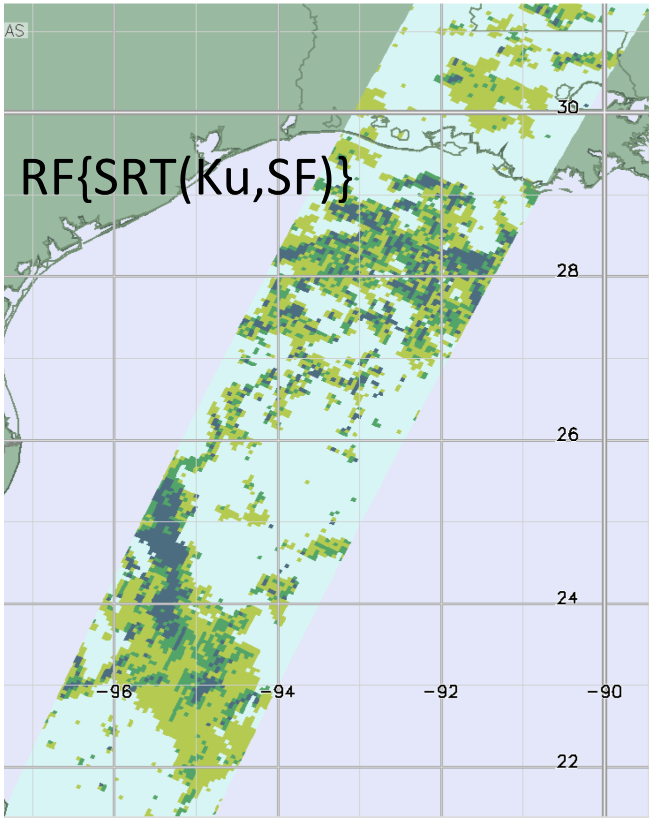
Reliability Flags for SRT(DF), left, and Hybrid(DF), right

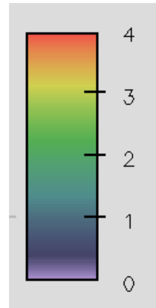


Ku-band PIA from Single-Freq Methods



Weight factors used in Single-Freq Hybrid Estimate of Ku-band PIA





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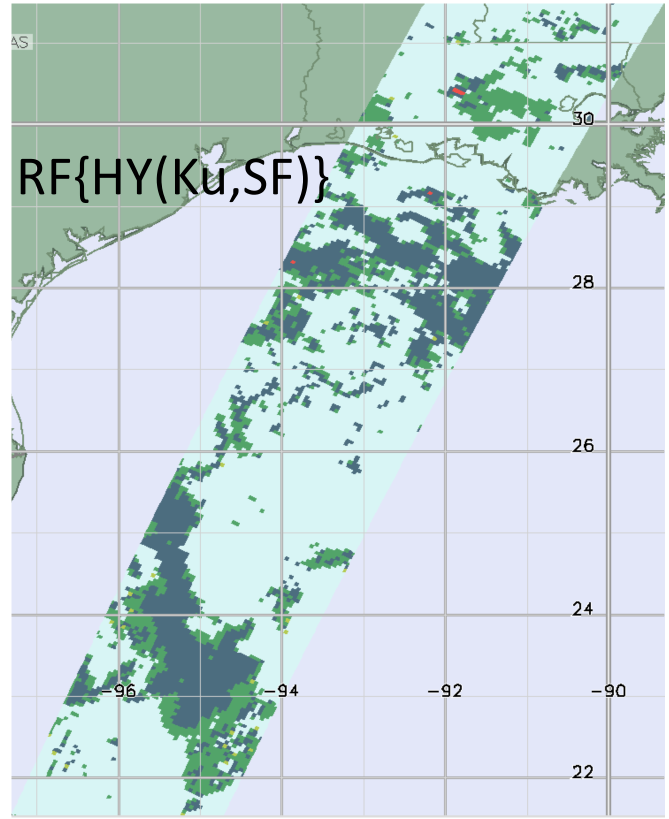
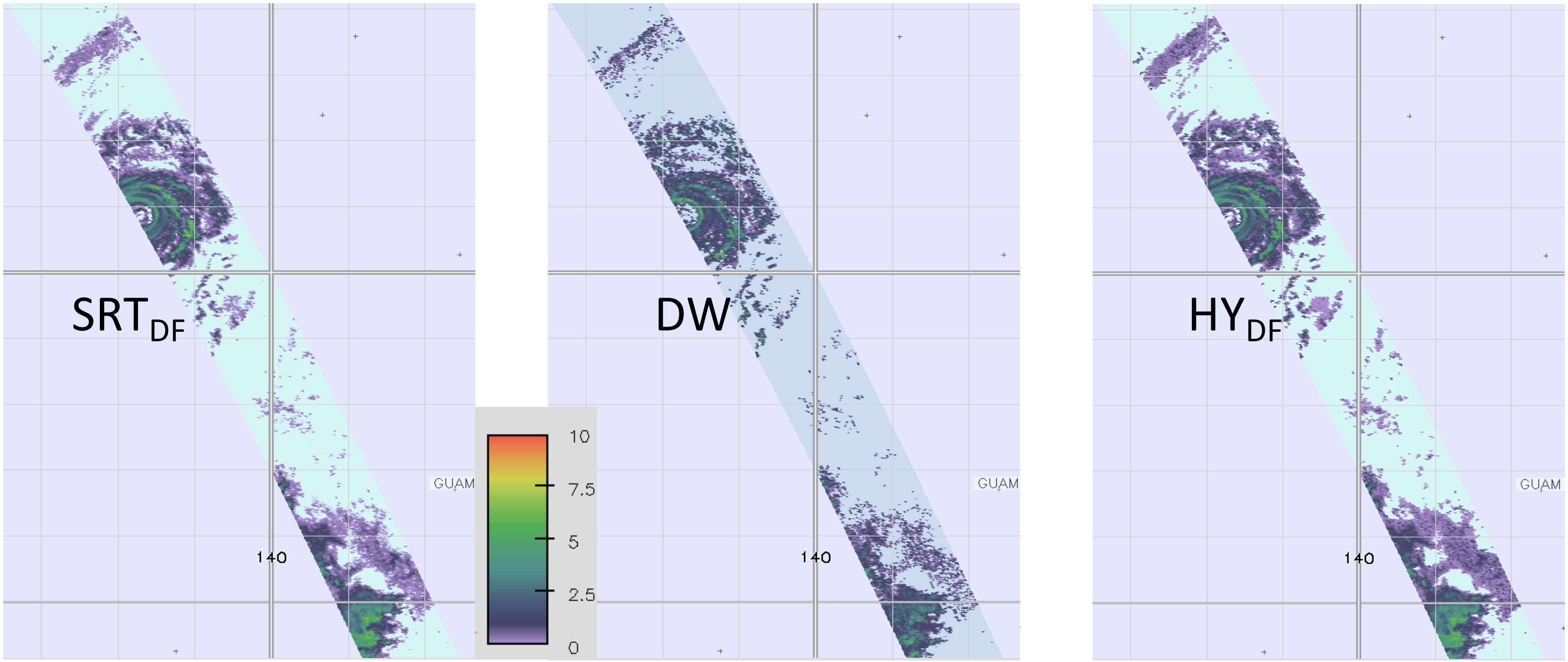


Reliability Flags for SRT(Ku, SF), left, and Hybrid(Ku, SF), right

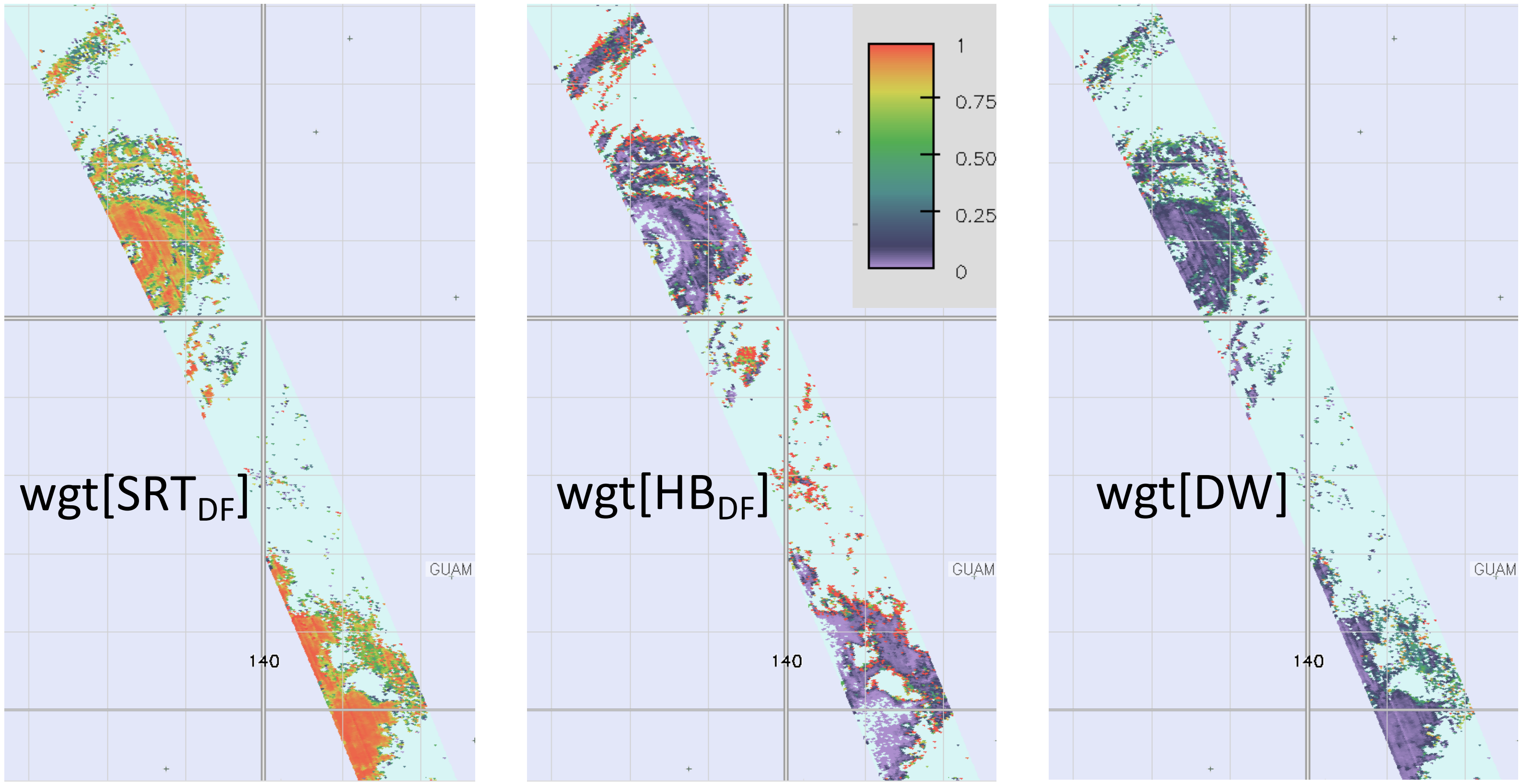
Case 2

- Orbit: 25601
- Date: 2018/08/31
- Location: Typhoon, East of the Philippines
- New Ka-band Scan

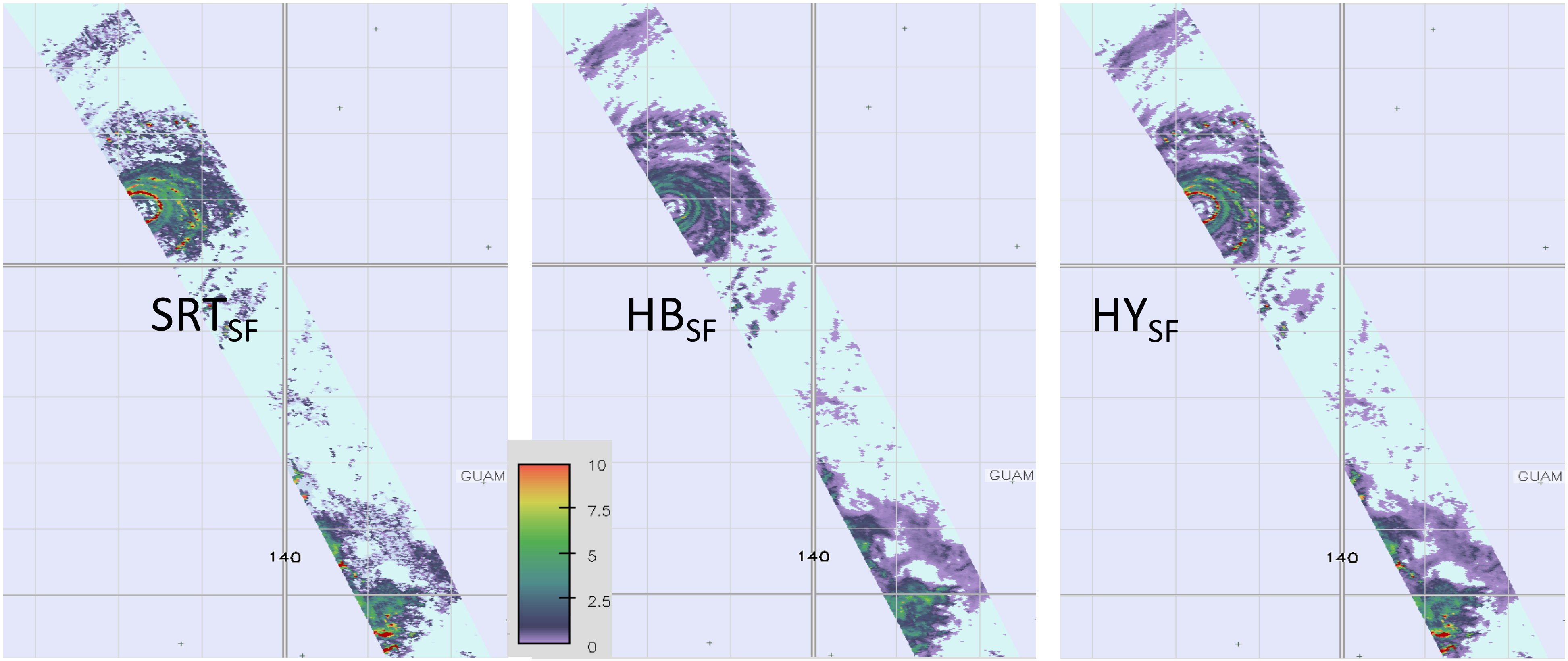


Ku-band PIA from Dual-Freq Methods

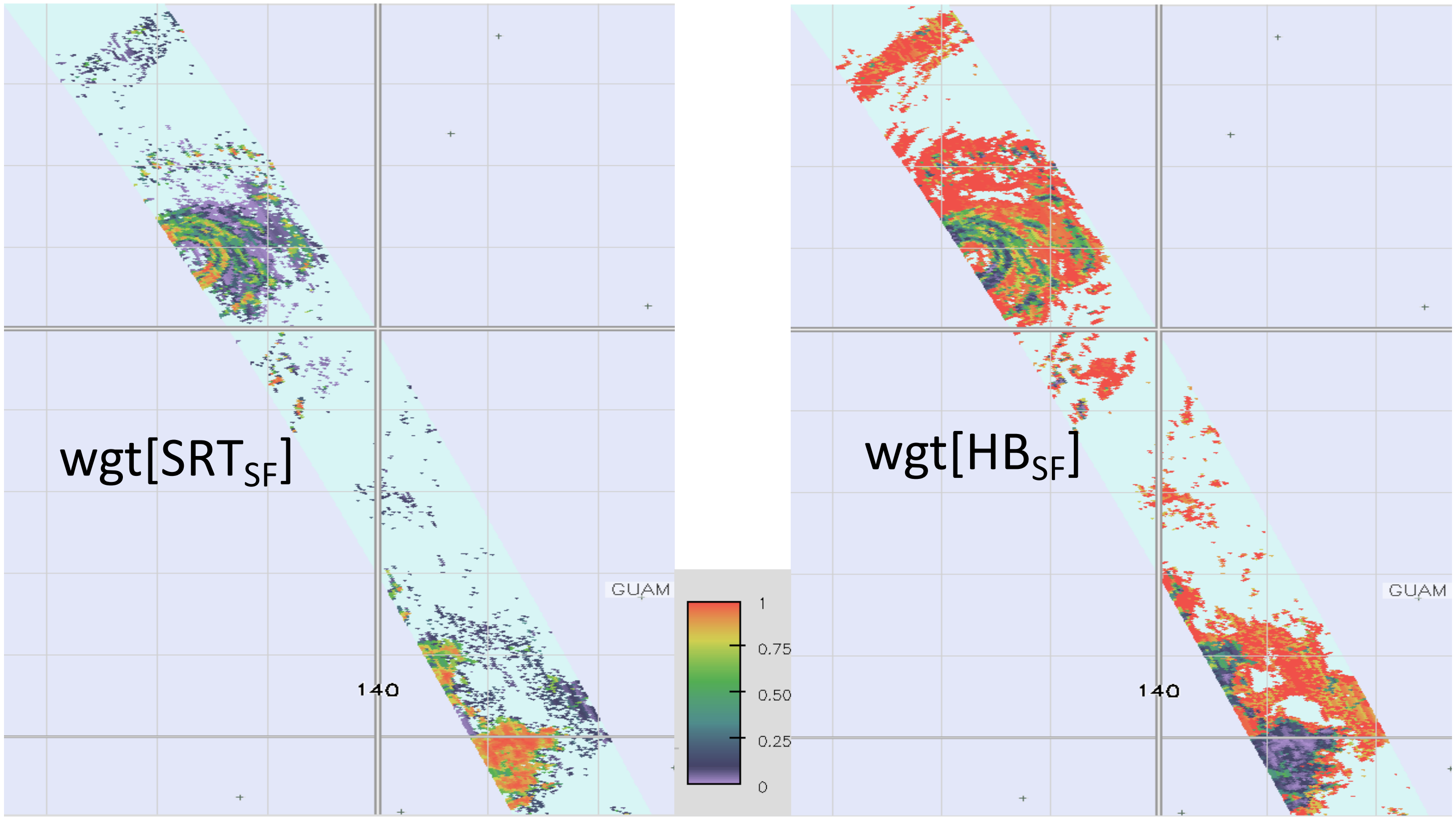
(HB_{DF} used in hybrid but not shown/saved)



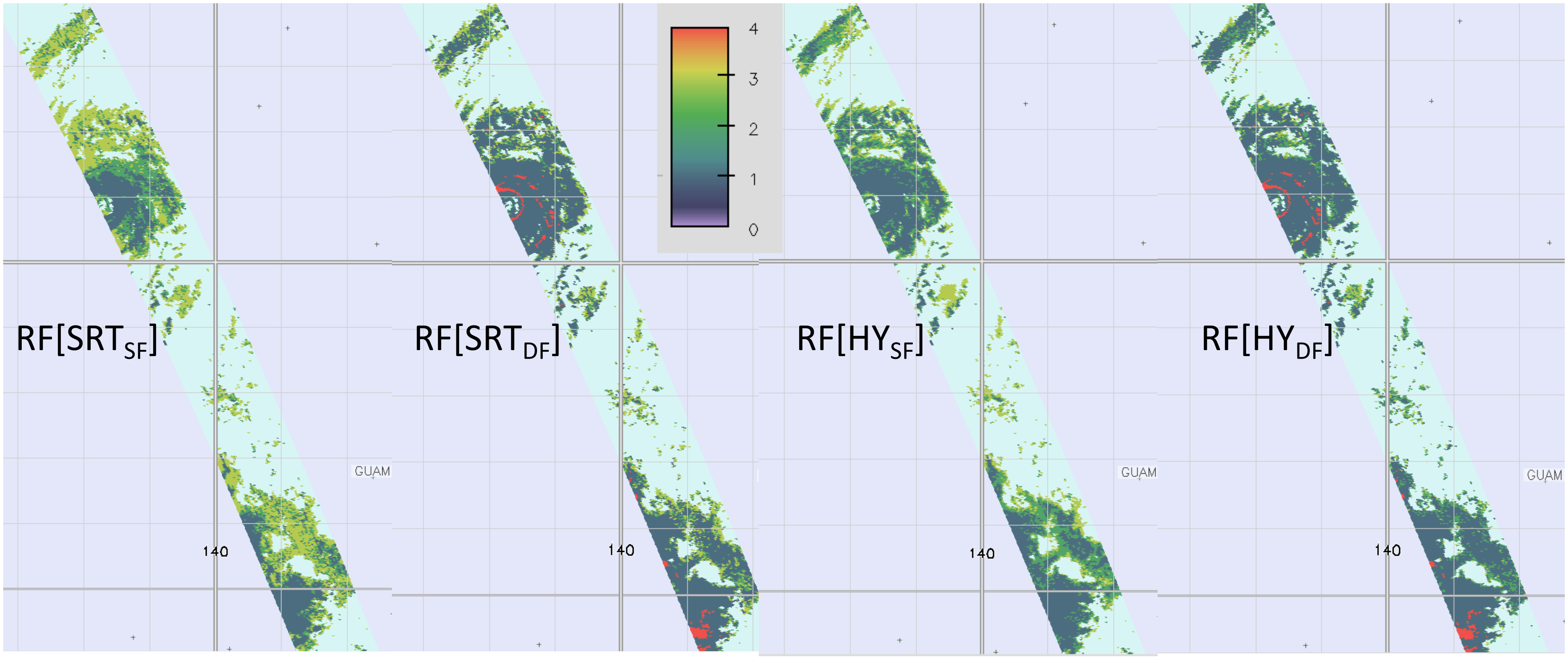
Weight factors used in Dual-Freq Hybrid Estimate of Ku-band PIA



Ku-band PIA from Single-Freq Methods



Weight factors used in Single-Freq Hybrid Estimate of Ku-band PIA



Reliability Flags at Ku-band for single/dual-freq SRT (left) and single/dual-freq Hybrid (right)

RF=1 if r>3 (blue)
RF=2 if 1<r<3 (green)
RF=3 of r<1 (yellow)
RF=4 if SNR<2 (red)

Summary

- σ^0 statistics from the new Ka-band full scan look good
  - DSRT can be used over the full swath with improved estimates of path attenuation
- The hybrid formulation is motivated by the desire to obtain the most accurate estimate of path attenuation by combining existing methods
- Results: Focus on preliminary results from the new data
- At moderate to high PIA, DSRT tends to be weighted most strongly, esp over ocean, followed by DW and HB
- At low values of PIA, HB tends to dominate

Summary - continued

- Reliability factor/flag indicates that hybrid estimate is more accurate than SRT/DSRT; for single-freq, significantly so

- Though the dual-freq results generally appear to be more accurate than those from single-freq, this is not the case when we have loss of rain or surface signal at Ka-band

- A critical part of the procedure depends on the variances assigned to the SRT, HB and DW

- Results are preliminary & there are issues to be addressed